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Trapezoidal Patch Resonator Bandpass Filter

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(Abstract) Isosceles trapezoidal resonator (TR) is analyzed. New trapezoidal resonator band pass filters with single band, dual-band and tri-band are proposed, and the designs are verified by experiment. It shows with fractal-shaped defection in patch, filter performance is greatly improved, and the band pass filters implement a controllable, dual-mode dual and tri-pass band with a maximum relative bandwidth of 38.1% and low pass band insertion loss. The designed filters have outstanding advantages of simple and compact structures without resonator coupling gaps, small sizes and multiple-band operation, and these features are very useful for applications in wireless communication systems.

Key words: Trapezoidal Resonator; Dual-mode; Dual and Tri-passband; Wide Band; Controllable Operation.

1. INTRODUCTION

Microstrip band pass filters play important roles in a variety of microwave circuits and systems. Recently, the increasing demand of wireless communication applications necessitates radio frequency (RF) transceivers operating at dual or multi-frequency bands in order that users can access various services with a single handset, so the dual-band or multi-band filters which are applied in a dual or multi-band wireless communication system are key circuit block in present communications. According to the reported works, dual-band filter is designed by directly cascading the two individual filters with two specified single passbands [1], and using stepped impedance resonator (SIR) structure [2,3] which controls the second passband by adjusting the impedance ratio and electric lengths of SIRs [4], or using more than two patch resonators to implement a dual-mode dual-band bandpass filter [5], et al. By comparison, single patch resonator dual-band filter is seldom reported.

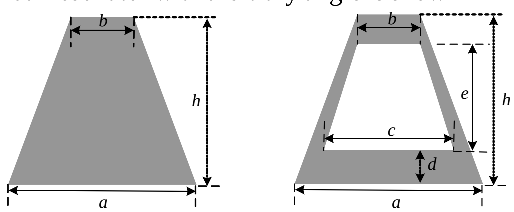
Fractal has inherent properties of self-similarity and space filling. The typical fractals with their shape and dimensions decided by certain mathematic method always are strictly self-similar, and can be called well-regulated or regular fractals. Those not-carefully-designed fractal configurations applied in RF circuit, however, are irregular fractals with rough self-similarity. In RF circuits design, Fractal-shaped patch defection [6,7] can change the current pattern of filter, and make it distributes along the flexual conductor surface instead of the original simple patch surface, so the electric length increased. On the other hand, the defection can act as filter perturbation and make the resonant frequencies excursion, introduce dual-mode or multi-mode operation, and suppress the higher order parasitical harmonics to implement multi-band or wide band [8] as well as miniaturization. In our design, trapezoidal patch defection is irregular fractal with rough self-similarity to the trapezoidal patch. We know a patch resonator has numerous resonant modes, and these modes and their degenerate modes have the same resonant frequencies if the resonator has not any physical perturbation. The patch resonator's dominant mode and its degenerate mode can be split if a proper perturbation is introduced, so, the dual-mode single patch filter can be equivalent to a dual-patch filter without perturbation, however, the circuit size can be reduced a half. The tradition dual-mode refers to the dominant mode and its degenerate mode, and many dual-mode filters are proposed by using all kinds of perturbations. In our research, it is shown that certain perturbation such as fractal patch defection not only introduces the dominant mode and its degenerate mode split, but also introduces the higher order mode and its degenerate mode split, and as a result, dual-mode dual and tri-band bandpass filters can be implemented by using a single patch resonator.

In this report, new types of microstrip bandpass filters using single isosceles trapezoidal resonator (TR) with fractal-shaped defection are designed for implementing good frequency selectivity, wide passband and upper stopband, and an extraordinarily required dual-band and tri-band performance. Some new rules are obtained at the same time. Compared with the triangular patch filter, the trapezoidal one has more parameters to control, and has smaller size because of the top triangle cut. Our design has a size reduction of 84.39% compared with [5], and a size reduction of 43.11% compared with [9] for which using a pair of triangular resonators to get better filter performances, and simultaneously, our design implements dual-band and tri-band operation. The designed filters have miniature and compact sizes without coupling gaps.

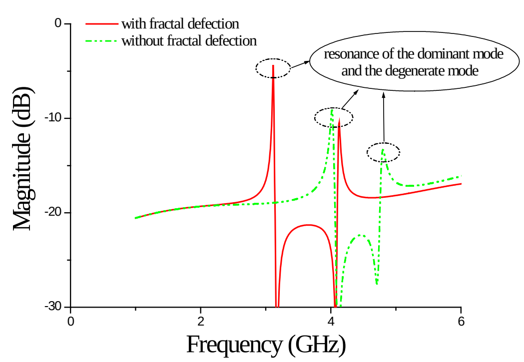
2. TRAPEZOIDAL PATCH RESONATOR

Trapezoidal resonator as shown in Fig.1(a) can be seen as a dual-mode one for it is the isosceles triangular resonator with a top triangle cut, and the cut brings a pair of degenerate modes splitting. If more perturbation such as a fractal-shaped defection is introduced, as is shown in Fig.1(b), more modes splitting occur and which will bring dual-mode dual-band operation, and wider passband is due to the coupling of the dual-mode. Simultaneously, this kind of structure has more geometric parameters for controlling, and which may bring better and new performance.

Simulated mode splitting performance of the trapezoidal resonator is shown in Fig.1(c), and it validates the judgment we draw above. It shows with fractal patch defection, resonance is enhanced, resonant frequency of the resonator decreases, and more splitting is introduced, and which is helpful for a wideband filter design. Calculated resonant performance of the trapezoidal resonator with arbitrary angle is shown in Fig.2, and



(a) Trapezoidal resonator (b) TR with fractal defection



(c) Dominant mode split

Fig.1 Dual-mode resonance of the trapezoidal resonator, a=h=12mm, b=4mm, c=8mm, e=6mm.

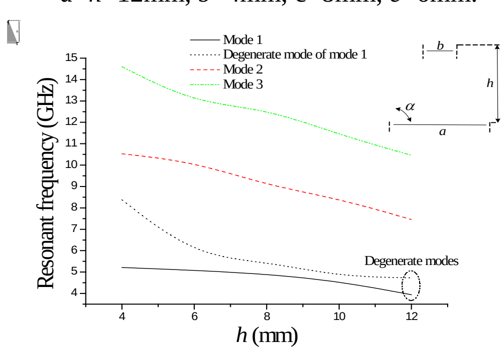


Fig.2 Resonant performance of the TR with arbitrary angle, a=12mm, b=4mm.

it can be seen that the resonant frequencies of the first three modes decrease with height h increases, and the dominant mode and its degenerate mode split. For a trapezoidal resonator with patch defection as shown in Fig.1(b), calculated curves of resonant frequency versus parameter c, parameter e and parameter d are shown in Fig.3, Fig.4 and Fig.5, respectively, and all of the figures show that the dominant mode and the first higher order mode of the TR split, and which is very useful for a dual-mode dual-band filter implementation. It can be seen from Fig.3 that the dominant mode and its degenerate mode have a shaper split when c increases, however, mode split of the first higher order mode nearly has no variation when c increases. It also shows resonant frequencies of the first degenerate mode, the first higher order mode and its degenerate mode as well as the second higher order mode have little variation when c increases. Fig.4 shows that split of the dominant mode and its degenerate mode has little variation when e increases, while, split of the first higher order mode and its degenerate mode lowers when e increases. Fig.4 also shows resonant frequencies of the dominant mode and its degenerate mode, and the degenerate mode of the first higher order mode decrease when e increases, while, it is opposite to the second higher order mode. Fig.5 shows that split of the dominant mode and its degenerate mode increases when d increases, while, for the first higher order mode and its degenerate mode, it shows the split lowers when d<2.1mm, while, the split increases when d>2.1mm. In the research, it is also shown that resonance of the second higher order mode becomes more and more weak when d<1.5mm, and at last it is suppressed. Transmission characteristics of the patch defected trapezoidal resonator is illustrated in Fig.6, and all of the resonators are designed to have the same resonant frequency of 3.04GHz. It can be seen that the first spurious response improves as the size of the resonator reduces, therefore, the TR with fractal defection has been miniaturized.

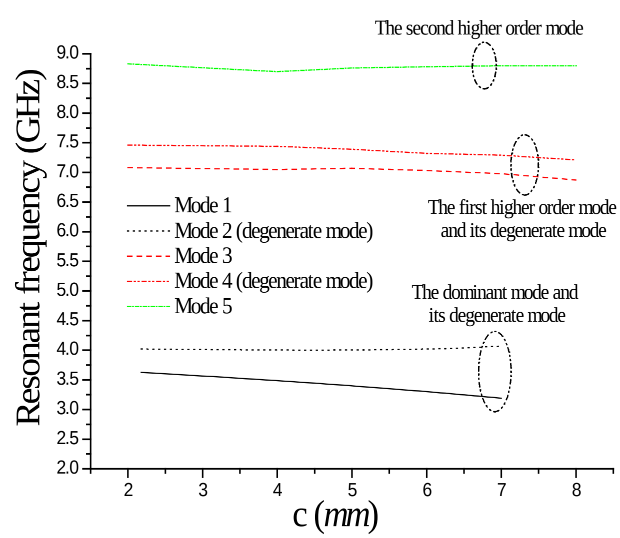


Fig.3 Relationships of resonant frequency and parameter c, a=h=12mm, b=4mm, d=2.8mm, e=6mm.

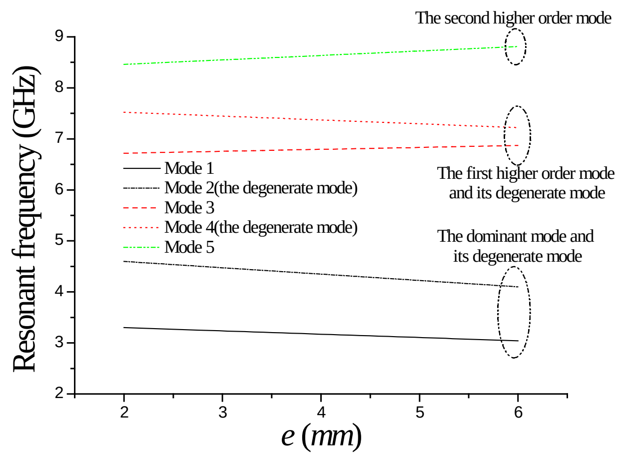


Fig.4 Relationships of resonant frequency and parameter *e*, *a*=*h*=12mm, *b*=4mm, *c*=8mm, *d*=2.8mm

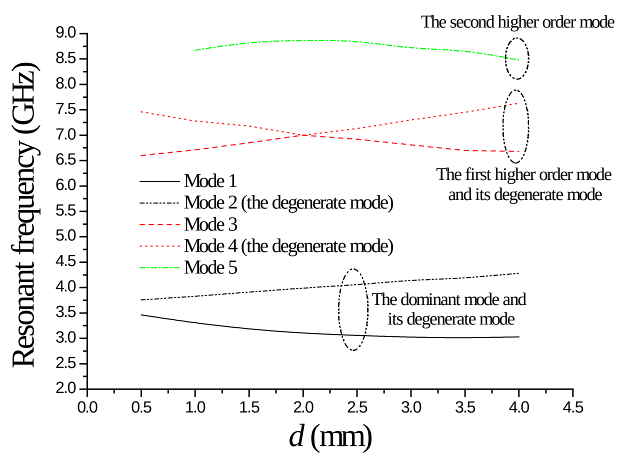


Fig.5 Relationships of resonant frequency and parameter *d*, *a*=*h*=12mm, *b*=4mm, *c*=8mm, *e*=6mm.

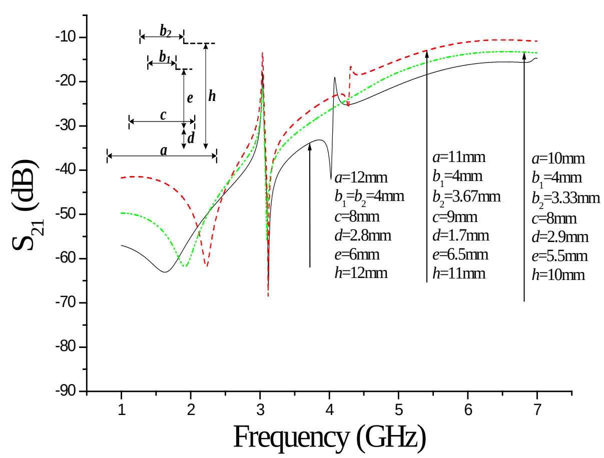
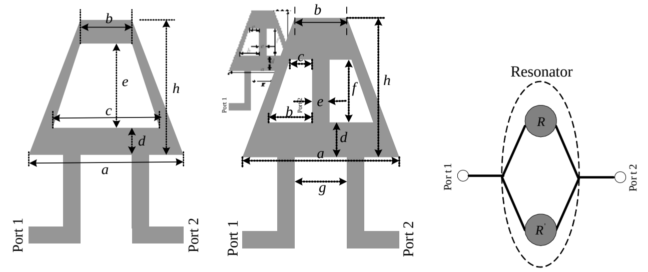


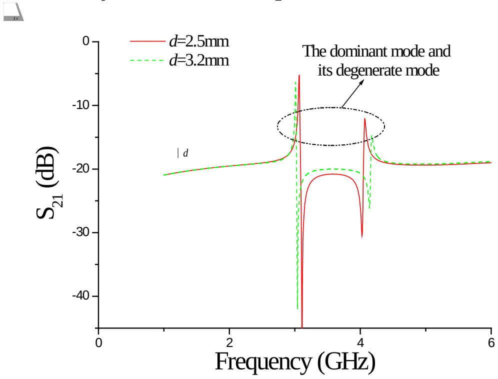
Fig.6 Transmission characteristics of the TR with fractal patch defection



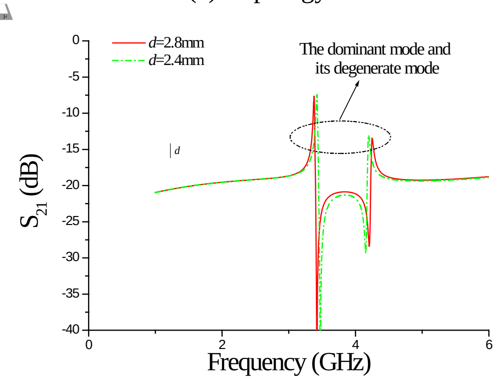
(a) Topology 1 (b) Topology 2 (c) coupling structure

Fig.7 Dual-mode trapezoidal resonator bandpass filters, (a) *a*=12mm, *b*=4mm, c=8mm, d=2.8mm, e=6mm, *h*=12mm, (b) *a*=12mm, b=4mm, c=2mm, d=2.8mm, e=1.2mm, *f*=5.7mm, *h*=12mm.

The external quality factor of a single resonator may be expressed as $Q_{ei} = f_{0i} / \Delta f_{3dB}$, where, Q_{ei} is the external quality factor of the *i*-th resonant mode, and f_{0i} and Δf_{3dB} are the *i*-th resonant frequency and the corresponding 3-dB bandwidth of the single patch resonator with fractal defection, when it is externally excited alone. It can be calculated for *a*=*h*=12mm, *b*=4mm, c=8mm and *e*=6mm, $20<Q_{e1}<60$, $Q_{e2}>100$. It shows that the presented trapezoidal patch resonator with fractal defection has adequate external quality factor which may introduce low passband insertion loss.



(a) Topology 1



(b) Topology 2

Fig.8 Mode split of the trapezoidal resonator with fractal patch defection

3. DUAL-MODE TR BANDPASS FILTER WITH WIDE BAND

The traditional dual-mode refers to the resonator dominant mode and its degenerate mode, and the dual-mode filter is realized by using certain perturbation which makes the dominant mode and the degenerate mode split, and their coupling introduces the desired result. Commonly, more perturbation brings about more split which introduces wider bandwidth. Here, trapezoidal resonator dual-mode bandpass filters are designed, as Fig.7 shows, and the mode split is plotted in Fig.8. It shows the fractal defection brings adequate mode split of more than 0.8GHz between the resonances of the dominant mode and its degenerate mode, while, larger value of parameter *d* introduces more mode split. Simulated frequency responses of the dual-mode bandpass filters are plotted in Fig.9, and it shows filter topology 1 and topology 2 have relative bandwidth of about 38% and 30%, respectively, both have passband insertion loss of no more than 0.3dB. In order to verify the design, the proposed filters as shown in Fig.7(a) and (b) are fabricated and measured, and the measurement is got by Agilent E5071C vector network analyzer. Fig.10 shows the fabrication (The relative dielectric constant of substrate is ε_r =10.2, and the loss angle tangent is $tan\delta$ =0.001) and measured results. It can be seen the measurements are similar to the simulations, and the measured passband insertion loss is less than 1.3dB. The current investigation uses a ceramic substrate with dielectric constant of 10.2, and a thickness of 1.27mm for all of the calculations and filters design.

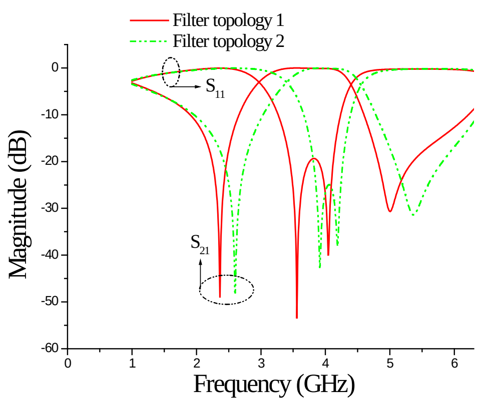
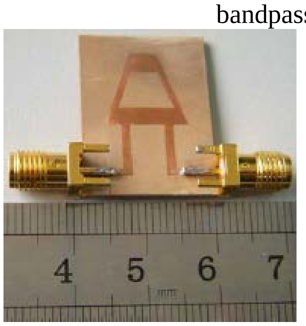
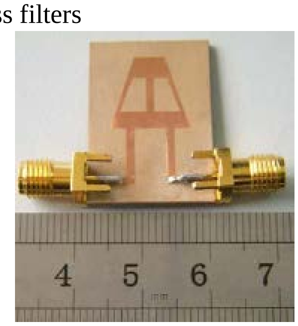


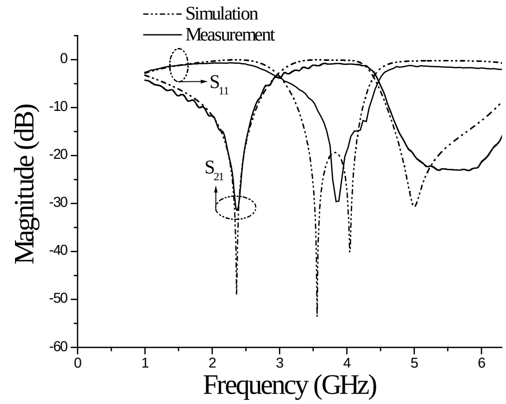
Fig.9 Simulated frequency responses of the dual-mode bandpass filters



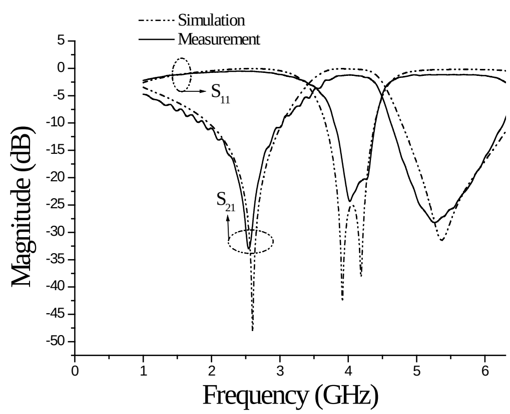
(a) hardware 1



(b) hardware 2



(c) Measured results of filter topology 1



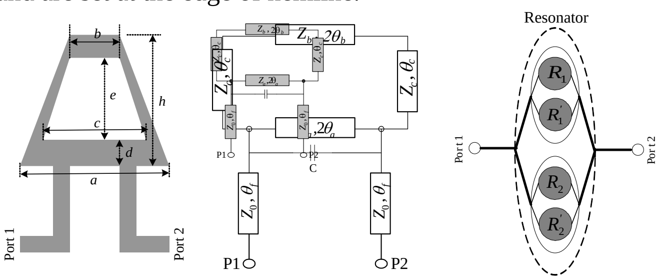
(d) Measured results of filter topology 2

Fig.10 Fabrication and measurement of the trapezoidal dual-mode bandpass filter

4. TRAPEZOIDAL RESONATOR BANDPASS FILTER WITH DUAL AND TRI-BAND

Section 3 described the traditional dual-mode filter with a single band, however, the dual-mode not only occurs to the dominant mode but also occurs to the resonator's higher order modes. The trapezoidal bandpass filter has more geometric parameters to control compared with a triangular filter, and especially the higher order dual-mode can be introduced with the help of a fractal patch defection. Here, we propose three kinds of bandpass filters by using a single trapezoidal patch resonator with fractal defection. Geometric structure of the proposed dual-mode dual-band bandpass filter model 1 is shown in Fig.11(a), and the rough circuit model and coupling structure are shown in Fig.11(b) and Fig.11(c), respectively, where, parameter *d* is the distance between the bottom lines of isosceles trapezoidal defection and isosceles trapezoidal patch. Fig.11(b) shows the equivalent transmission line model, in which the TR with fractal defection can be approximately modeled using connections of transmission lines with (Z_a , $2\theta_a$), (Z_b , $2\theta_b$) and (Z_c , θ_c) because of symmetrical. Where, Z is the characteristic impedance, $2\theta_a$ is the electric

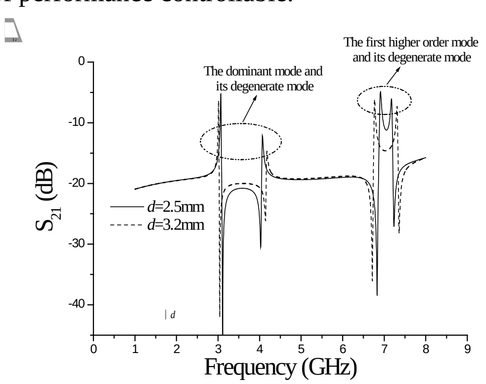
length of TR hemline, $2\theta_b$ is the electric length of TR upper line, θ_c is the electric length of the triangle bevel line, and θ_f is the electric length of microstrip feed line. Here, $\theta = \beta l$, β is the phase-shift constant of microstrip line, and l is the corresponding physical length. R_i denotes the i-th resonator which is corresponding to the i-th mode, and $R_i^{'}$ denotes the resonator corresponding to the i-th degenerate mode, i=1,2. Fig.11(c) shows that the coupling of R_1 and $R_1^{'}$ introduces the first passband, similarly, the coupling of R_2 and $R_2^{'}$ introduces the second passband. Isosceles trapezoidal defection is etched in the isosceles trapezoidal metal patch in order for introducing perturbation to the resonant modes. The I/O feed lines are parallel microstrip lines with characteristic impedance of 50 Ω and are set at the edge of hemline.



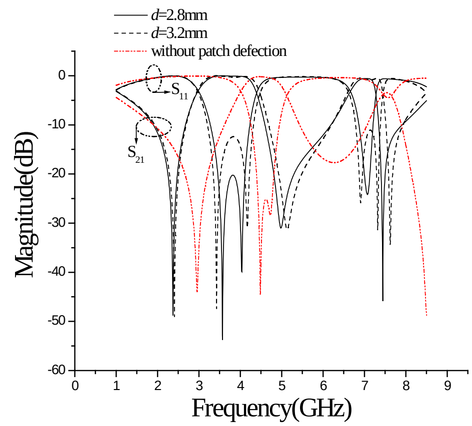
(a) Topology (b) Equivalent circuit (c) coupling structure

Fig.11 Trapezoidal dual-mode dual-band bandpass filter model 1, a=12mm, b=4mm, c=8mm, d=2.8mm, e=6mm, h=12mm.

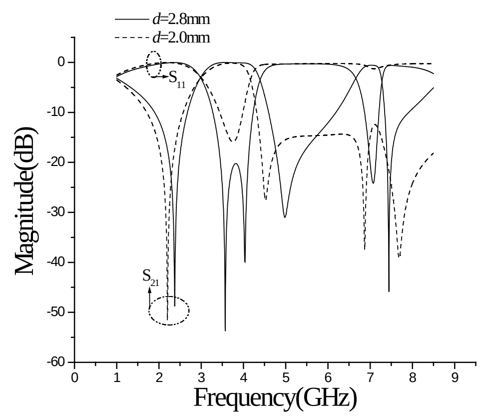
Fig.12 plots the simulated results. Fig.12(a) shows the mode split of the dominant mode and the first higher order mode for the trapezoidal resonator by using weak coupling, and it can be seen that the mode split not only includes the dominant mode and its degenerate mode, but also includes the first higher order mode and its degenerate mode, and which introduce the dual-mode dual-band bandpass filter. It can be seen from Fig.12(b) that when d=2.8mm, the dual-band bandpass filter operates at 3.67GHz and 6.97GHz, with corresponding relative bandwidth of 38.1% and 8.5%, respectively, and has low passband insertion loss of no more than 0.6dB. It also shows that the filter performance is greatly improved by using fractal defection. Fig.12(c) shows that when d decreases to 2.0mm, the second passband response is suppressed and the upper stopband is greatly extended, so, this kind of filter has an extraordinary virtue of performance controllable.



(a) Mode split of the trapezoidal resonator

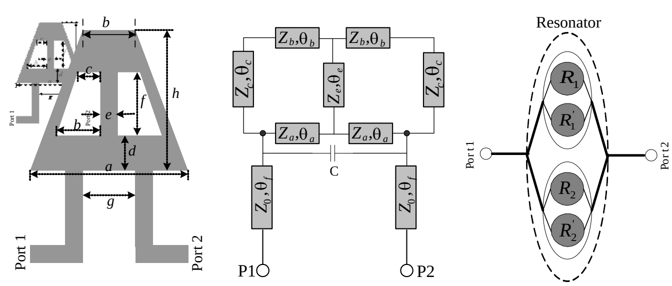


(b) Filter dual-band responses



(c) Filter frequency responses comparison

Fig.12 Simulations of the dual-mode dual-band bandpass filter

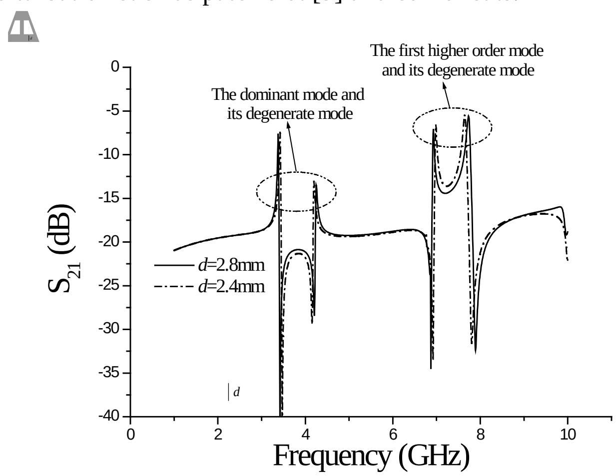


(a) Topology (b) Equivalent circuit (c) coupling structure

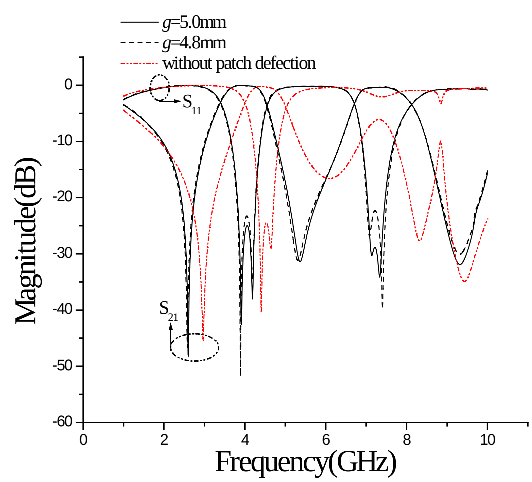
Fig.13 Trapezoidal dual-mode dual-band bandpass filter model 2, a=12mm, b=4mm, c=2mm, d=2.8mm, e=1.2mm, f=5.7mm, h=12mm.

Filter topology, approximate transmission line model and coupling structure of the proposed dual-mode dual-band filter model 2 are shown in Fig.13(a), (b) and (c), respectively. Here, two fractal defections are introduced for the modes split. Simulated filter frequency responses are shown in Fig.14, it can be seen that when g=5.0mm, the dual passbands center at 3.96GHz with a relative bandwidth of 29.5% and a maximum passband insertion loss of 0.2dB, and 7.42GHz with a relative

bandwidth of 18.6% and maximum passband insertion loss of 0.4dB, respectively. Fig.14(a) shows the mode split of the trapezoidal resonator with a pair of defection cells, and it can be seen that for this kind of perturbation, the first higher order mode and the degenerate mode split more compared with that shown in Fig.12(a). It also shows the fractal defection brings greater and more modes split compared with the other perturbation such as patch slot [9] and corner cuts.

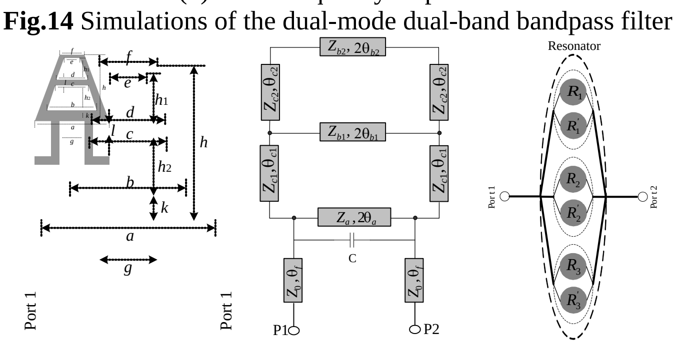


(a) Mode split of the trapezoidal resonator



(b) Filter frequency responses

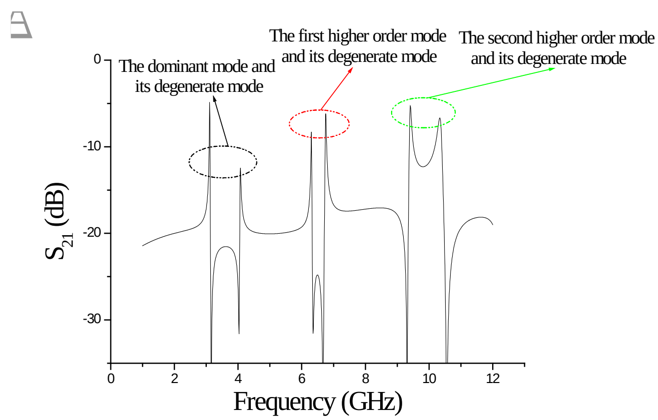
Fig.14 Simulations of the dual-mode dual-band bandpass filter



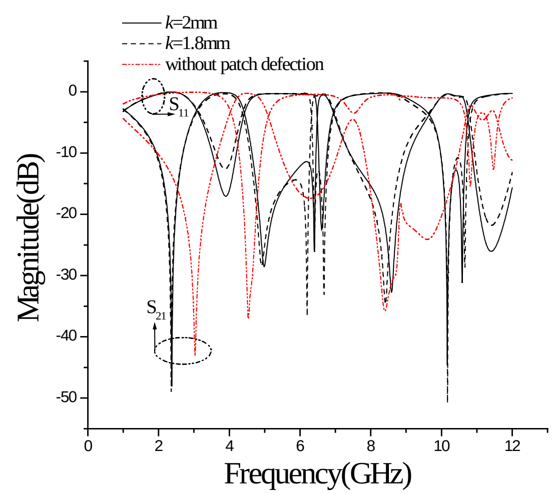
(a) Topology (b) Equivalent circuit (c) coupling structure

Fig.15 Trapezoidal dual-mode tri-band bandpass filter, a=12mm, b=8.6mm, c=5.4mm, d=5mm, e=3mm, f=4mm, h=12mm, h_1=3.5mm, h_2=5mm, k=2mm, l=1mm.

Except for the trapezoidal filters with a single defection and a pair of defections, a dual-mode tri-band bandpass filter with different fractal defection cells is also proposed, as Fig.15(a) shows, and the approximate transmission line model and coupling structure are shown in Fig.15(b) and (c), respectively. Fig.16 shows the simulated frequency responses of the bandpass filter, which operates at 3.73GHz, 6.72GHz and 10.23GHz, with corresponding relative bandwidth of 36.7%, 7% and 9.6%, respectively. Mode split of the trapezoidal resonator with different patch defections is shown in Fig.16(a), and it illustrates that all of the first three resonant modes (denoted by R_j, j=1,2,3) and their degenerate modes(denoted by $R_j^{'}$) split with the perturbation of the different fractal patch defections, and which introduces a dual-mode tri-band bandpass filter.



(a) Mode split of the trapezoidal resonator



(b) Filter frequency responses

Fig.16 Simulations of the trapezoidal dual-mode tri-band bandpass filter

5. CONCLUSIONS

Single trapezoidal patch resonator bandpass filters with a single wide band, dual-band and tri-band are proposed with the assistance of dual-mode operation, and the designs are demonstrated by experiment. The new design shows that the filter is controllable because the second passband can be suppressed when it is not required, and the suppression introduces an ultra-wide stopband. The research also shows that bandwidth of passband for a single trapezoidal patch bandpass filter is related with the size and geometric structure of defection, and a longer electric length brings wider passband. Compared with relative references, the new filters have compact structures without coupling gaps, low insertion loss inside the passband, and obvious size reduction by comparison with relative reports. All these features are popular for microwave circuits in wireless communication systems.

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